TECHNICAL PLANNING ACTIVITY

TPA

Executive Summary

Prepared for the
Office of Fusion Energy
U.S. Department of Energy

January 1987

Argonne National Laboratory, Argonne, Illinois
Operated by the University of Chicago
for the U.S. Department of Energy
under Contract W-31-109-Eng-38

MAGNETIC FUSION
TECHNICAL PLANNING ACTIVITY

EXECUTIVE SUMMARY

This summary report highlights the work of the Technical Planning Activity (TPA), which was commissioned in April 1985 by the U.S. Department of Energy's (DOE's) Office of Fusion Energy. The purpose of the TPA is to develop a technical planning methodology and to prepare technical plans in support of the strategic and policy framework of the Magnetic Fusion Program Plan (MFPP), issued by DOE in February 1985.[1] This work will also provide valuable technical input to subsequent international planning activities. There has been broad participation of the magnetic fusion community through the TPA Steering Committee, composed of more than 30 senior technical leaders. Complete details of this 18-month effort can be found in the steering committee's final report.[2]

MOTIVATION FOR TECHNICAL PLANNING

Fusion promises a safe, economical, and environmentally attractive energy resource based on a secure, essentially unlimited fuel supply. Fusion has a broad range of potential applications, including the production of electricity, fissile fuels, synthetic fuels, and high-grade heat for industrial applications. These prospects have led the major industrialized nations to vigorously pursue programs aimed at harnessing the energy released by fusion reactions, chiefly by using magnetic fields to confine high-temperature plasmas. In addition to making continuous and dramatic progress toward the goal of fusion power, magnetic confinement fusion programs have been an important source of new scientific insights and technological developments that go far beyond energy applications.

Demonstrating an economically competitive fusion energy source is a challenge that requires major scientific and technological advances. In seeking to meet this challenge, fusion research has progressed from exploratory studies in the 1950s and 1960s to ever more sophisticated and ambitious undertakings. The significant progress made on all fronts during the past decade provides confidence that the challenge will be met.

Recent advances, particularly the achievement of plasma conditions approximating those of a fusion power source, provide the technical basis for defining a program plan to advance fusion research. The MFPP, which identifies key technical issues and strategic objectives and outlines an overall strategy for fusion research through the end of the century, provides the framework for such a plan. The TPA was established to formulate more detailed technical plans supporting this framework. It will facilitate informed decision making on a variety of research and development issues and ultimately on the prospects for commercial applications.

TPA APPROACH

The goal of the magnetic fusion program is to establish the scientific and technological base required to assess the economic and environmental aspects of fusion energy. This assessment is projected to occur by about 2005, although clearly the timing will depend on the pace of the program. In structuring a set of technical programs to achieve this goal, a planning horizon of 15-20 years has been adopted, with the greatest attention to detail devoted to the first five years.

The entire planning activity has focused on four key technical issues identified in the MFPP:

Magnetic Confinement Systems. Developing an understanding of the plasma science concepts suitable for commercial applications of fusion energy.

Properties of Burning Plasmas. Understanding the effects introduced when the plasma is internally heated by the fusion reaction.

Fusion Nuclear Technologies. Developing nuclear technologies unique to the commercial application of fusion energy.

Fusion Materials. Developing materials that will enhance the economic and environmental potential of fusion.

Both the technical objectives of the program and the exposition of the planning information have been formulated in a way that is directly traceable to the MFPP through this set of key technical issues. The comprehensive approach undertaken by the TPA (depicted in Fig. 1) has required that a balance be maintained between a near-term perspective, focused primarily on the research tasks required to resolve the four key technical issues, and a long-term perspective, focused on the overall goal of the program.

The planning methodology developed for the TPA (Fig. 2) adheres to the overall policy and strategy articulated in the MFPP. The TPA subdivided the MFPP's four key technical issues into more narrowly defined issues, each of which must be resolved in order to meet the overall program goal. For each issue, a technical objective was specified to define what would constitute resolution of the issue. A set of program elements (and supporting subelements) was then defined for six major planning areas (Fig. 3), where each element represents a portion of the fusion program for which the technical issues and objectives are closely related.

A hierarchy of logic diagrams (corresponding to the planning structure shown in Fig. 3) was created to show key decisions and milestones. Facilities that are required to carry out the technical work were identified. In addition,

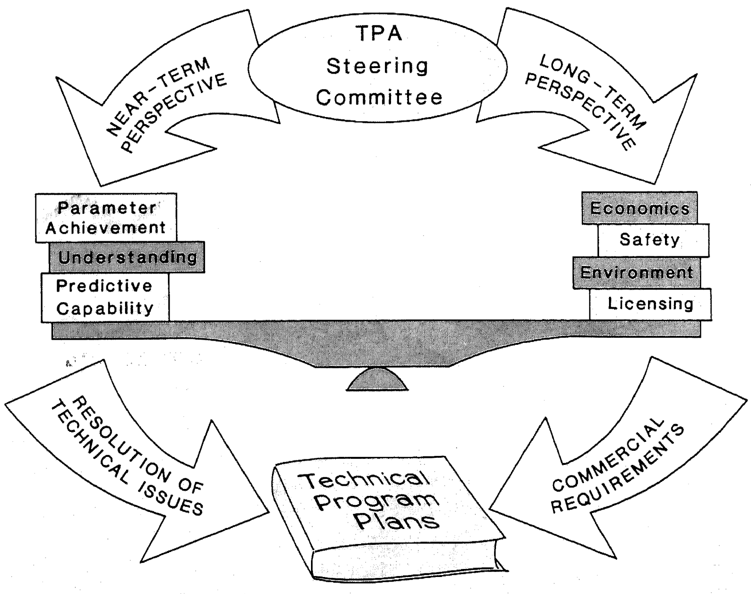


FIGURE 1 Balancing of Near-Term and Long-Term Perspectives in Developing Technical Program Plans

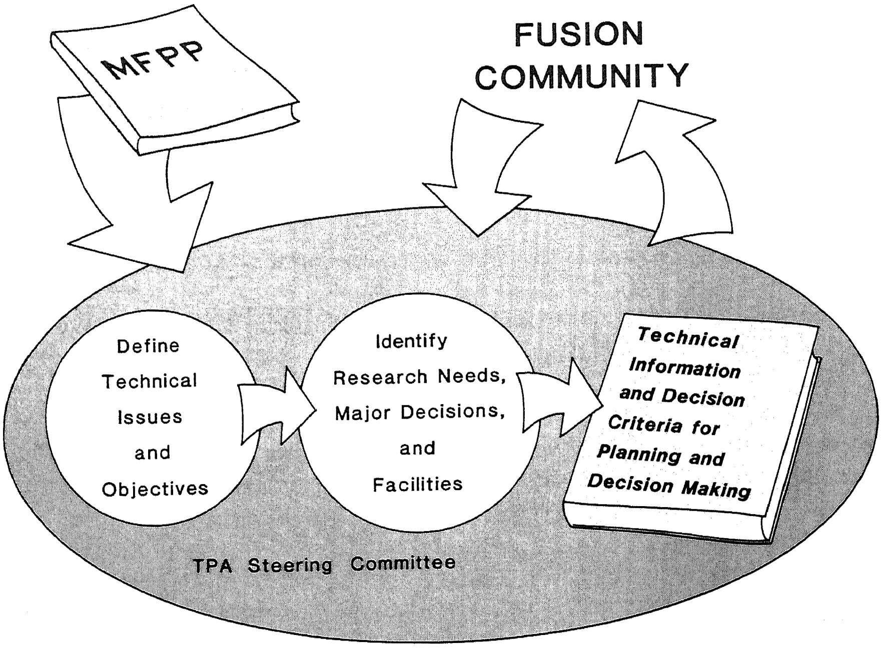


FIGURE 2 Schematic Representation of TPA Approach

descriptions of major programmatic decisions were prepared. Each decision description includes technical criteria on which the decision will be based, sources of information, and possible outcomes and consequences. Collectively, this information provides a basis for fusion planning and decision making.

SUMMARY OF OBJECTIVES AND TASKS FOR PLANNING AREAS

Confinement Systems. The objectives for the development of magnetic confinement systems are to demonstrate reactor-level plasma conditions for commercially attractive confinement concepts and to develop a sufficient predictive capability to design and optimize fusion systems for commercial applications. This predictive capability will be based both on empirical models derived from experimental data and on theoretical models. Both of the objectives are important in developing attractive concepts and producing an adequate

Confinement Systems
Late 1980s to Mid-1990s: Identify potentially attractive reactor concepts and address critical technical issues. ***Mid-1990s to Early 2000s:*** Perform experimental tests of promising concepts at reactor-level plasma conditions and develop related plasma-science predictive capability.

Burning Plasmas. The overall objectives of the burning plasma area are to demonstrate high fusion energy gain with sufficient pulse length and to develop the science and technology of burning plasmas. The approach is to follow the scientific breakeven experiments of the late 1980s with a short-pulse ignition tokamak, slated for startup around 1992. A more ambitious long-burn demonstration is anticipated before 2000. Although this long-burn device will provide all the information needed to resolve the burning plasma issue for a tokamak reactor, supplementary information may be required for other confinement concepts. The essential characteristics of the burning plasma tasks are summarized as follows:

Burning Plasmas
Late 1980s: Demonstrate scientific breakeven in one concept. ***Early 1990s:*** Achieve short-pulse ignition and study physics of alpha-particle-heated plasmas. ***Mid-1990s to Early 2000s:*** Produce and control a long-burn high fusion energy gain plasma and resolve critical plasma physics and technology issues.

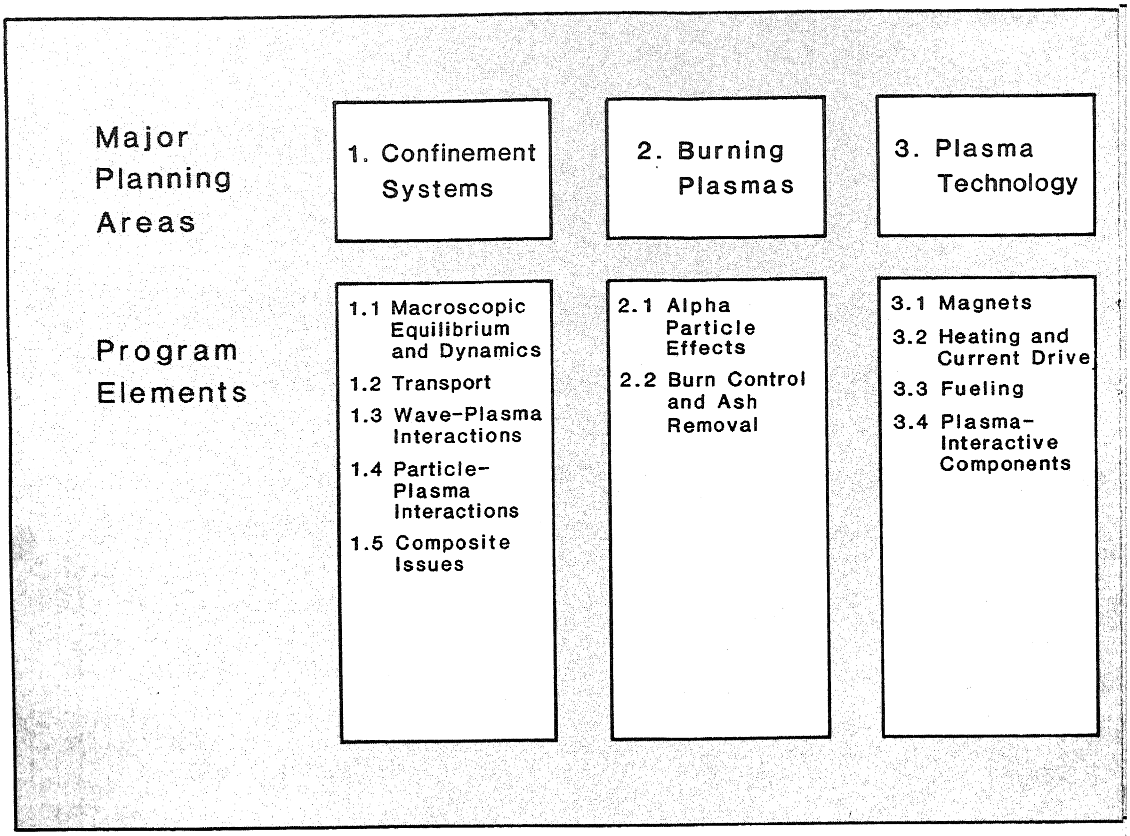


FIGURE 3 Major Planning Areas and Program Elements under the Technical Planning Activity

Plasma Technology. The objective of research and development in plasma technology (which deals with components that directly produce, confine, and control the plasma) is to provide continuing support to confinement systems devices, as well as critical input to the decisions involving each major facility. As such, the program is closely tied to the anticipated schedules for construction and operation of plasma experimental devices. The essential characteristics of the plasma technology tasks are summarized as follows:

4. Nuclear Technology	5. Materials	6. Systems Design and Analysis
4.1 Blanket/ First Wall 4.2 Shield 4.3 Tritium Processing 4.4 Nuclear Elements of Plasma-Interactive Components	5.1 Structural Materials 5.2 Nonstructural Blanket Materials 5.3 Special Materials	6.1 Applications, Economics, and Technology Transfer 6.2 Fusion Test Facilities, Critical Issues, and Development Pathways 6.3 Safety, Environment, and Licensing 6.4 Remote Technology 6.5 Alternative Fuel Cycles

Plasma Technology

Late 1980s: Perform subsystem feasibility tests on existing devices. Develop components for ignition demonstration.

Early 1990s: Perform tests on ignition device. Evaluate and develop components for long-burn demonstration.

Late 1990s: Develop components for testing in long-burn demonstration.

Early 2000s: Develop advanced systems based on quasisteady-state testing in fusion environment.

Nuclear Technology. The objective for the nuclear technology area is to develop nuclear fusion technology that leads to commercial fusion applications with attractive economic, safety, and environmental features. Initial research efforts will focus on scoping experiments that will explore basic properties and phenomena. The emphasis of subsequent research will gradually shift to multiple-effects tests, with progressively more sophisticated combinations of effects that simulate component service conditions. The essential characteristics of the nuclear technology tasks are summarized as follows:

Nuclear Technology
Late 1980s: Perform separate-effects tests and obtain scoping data. Provide input for short-pulse ignition demonstration.
Early 1990s: Perform multiple-effects tests to explore and characterize phenomena. Demonstrate nuclear technology needed for long-burn demonstration.
Late 1990s: Perform integrated tests in non-fusion facilities. Evaluate designs and provide components for long-burn demonstration.
Early 2000s: Demonstrate reactor-level nuclear technology in fusion environment.

Fusion Materials. The overall objective in the fusion materials area is to develop improved materials that will enhance the economic, safety, and environmental features for commercially competitive fusion applications. In order to reduce waste management requirements and enhance the potential for recycling of material, materials with low, long-term activation are emphasized. The primary focus of the materials program is the development of materials that will provide high performance and long lifetime in the unique environment of high-energy (up to 14 MeV) neutron radiation in a deuterium/tritium fusion reactor. The essential characteristics of the fusion materials tasks are summarized as follows:

Fusion Materials

Late 1980s: Provide baseline and low-fluence (fission) irradiation data and select candidate matérials for further demonstration.

Early 1990s: Provide reference baseline data and moderate-fluence (fission) irradiation data on primary candidate materials.

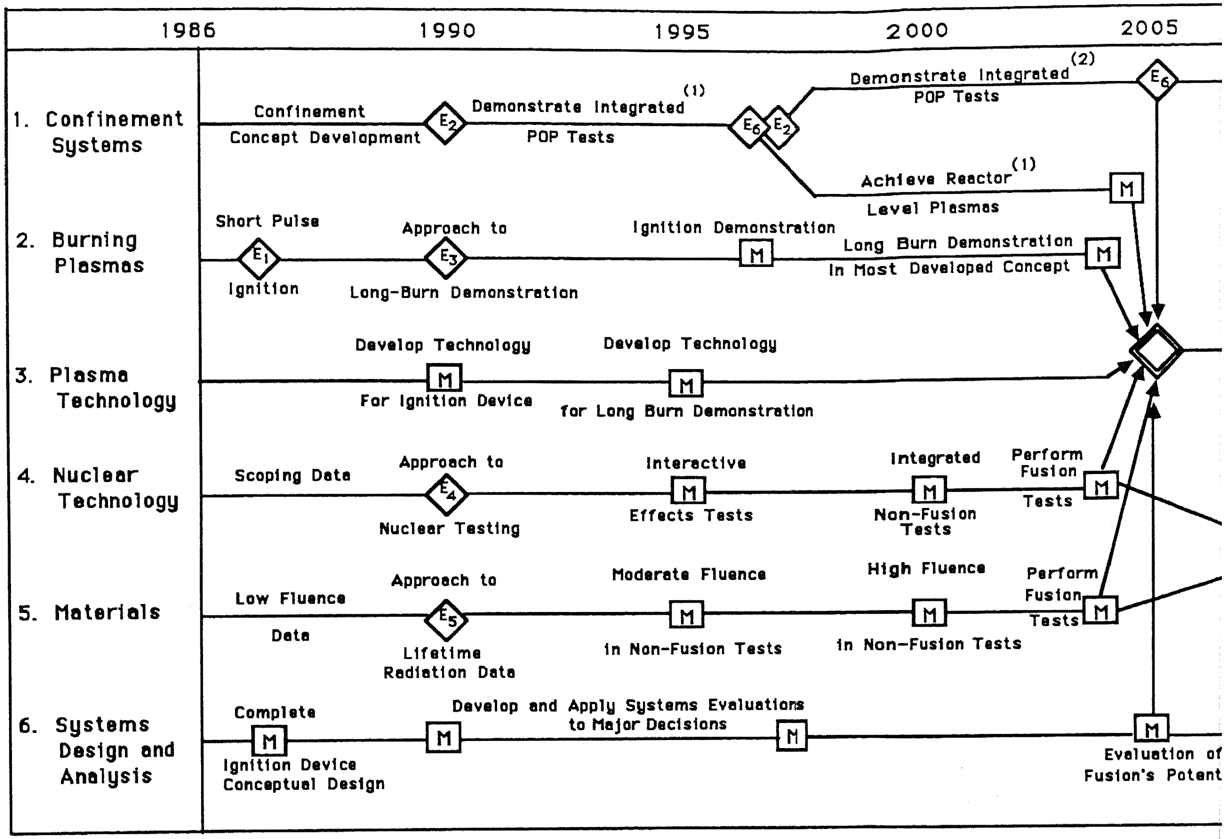
Late 1990s: Evaluate performance of primary candidate materials on the basis of high-fluence fission reactor data.

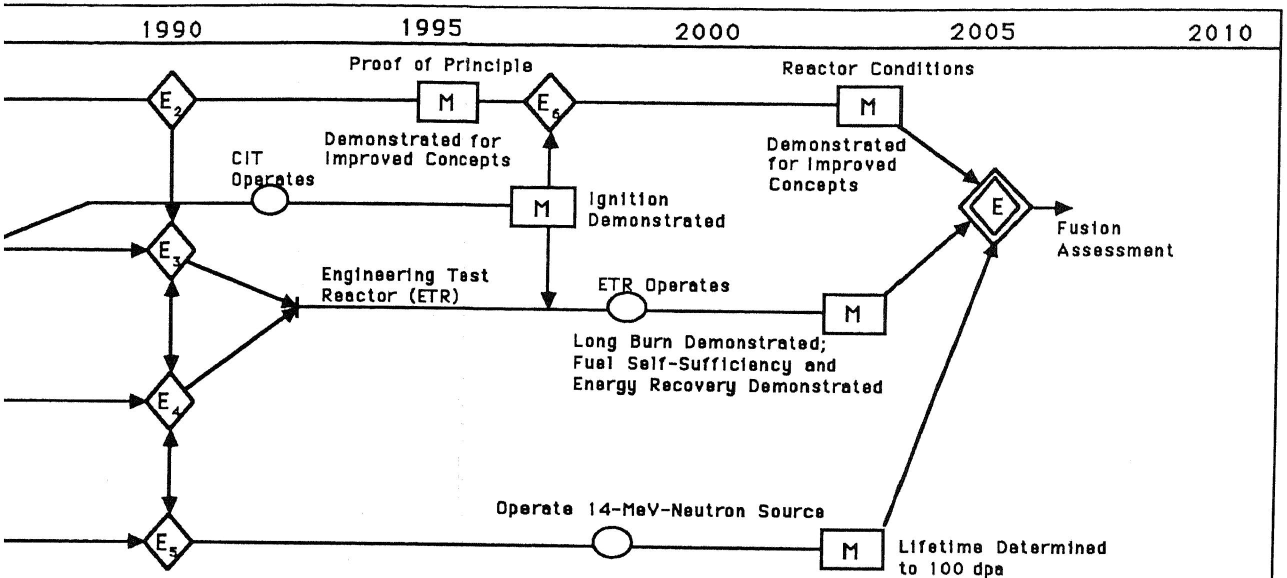
Early 2000s: Evaluate performance of reference material on the basis of moderate-to-high-fluence (14 MeV) neutron irradiation data.

Systems Design and Analysis. The overall objectives of the systems design and analysis area are to support the major program evaluation and decision tasks and to guide fusion R&D toward practical products. The activities will include the identification and resolution of critical issues that involve the interaction of plasma physics and technology, the maintenance of an engineering data base, and the setting of subsystem objectives based upon the identification of desired characteristics of commercial fusion applications with regard to economics, safety, and the environment. The essential characteristics of the systems design and analysis tasks are summarized as follows:

(1) From class of present "moderately-developed" concepts

(2) From class of present 'developing" concepts





:
- Short-pulse ignition (CIT) device is undertaken.
- An Engineering Test Reactor (ETR) is used for long-burn demonstration and nuclear-technology testing with limited lifetime data.
- Confinement-concept development proceeds in parallel with ignition long/burn demonstration.
- Materials irradiation lifetime data is available from a 14-MeV-neutron source.

demonstration (E_3), are complex and are paced by a variety of considerations, including budget levels and international agreements. One particular sequence of program decisions, called the "reference scenario," was the focus of the TPA effort.

The reference scenario (Fig. 5) includes a short-pulse ignition experiment, called the Compact Ignition Tokamak (CIT), and later a superconducting tokamak, called the Engineering Test Reactor (ETR). The ETR would have sufficient availability and neutron wall loading for nuclear technology testing and would also meet the needs of a long-burn demonstration. The nature and timing of these facilities are

TABLE 1 Major Fusion Decision Points

Decision Point	Description
E_1	Decide whether to proceed with a short-pulse ignition test in a compact ignition tokamak (1986-87).
E_2	Decide which confinement concepts should proceed to integrated proof-of-principle tests (~1990-91).
E_3	Decide on the approach to be followed regarding a long-burn demonstration (~1990).
E_4	Decide on the approach to be followed regarding nuclear technology testing in the fusion environment (~1990).
E_5	Decide on the approach to be followed in obtaining materials lifetime data in the fusion environment (~1990).
E_6	Decide whether additional confinement concepts should proceed to reactor condition tests (~1997).

consistent with current planning in the U.S. program and with recent international discussions that are an ongoing part of the Economic and U.S.-U.S.S.R. Summit Processes.

Confinement systems concept development proceeds through the integrated proof-of-principle (E_2) and reactor-condition (E_6) stages in parallel with resolution of the other three key issues. The reference scenario for concept development can be specified in some detail with confidence only for the tokamak concept, because other concepts are at an earlier stage of development. The number and timing of concept development tests for non-tokamak confinement concepts can only be decided after progress in this research has been reviewed in the context of overall program need. The criteria for determining program need will be defined by the rate of tokamak scientific and technical progress and by a continuing assessment of the attractiveness of the tokamak-based power system flowing from this progress.

The reference scenario also includes a materials test facility using 14 MeV neutrons. This facility provides sufficient yearly fluence for testing materials properties at a significant fraction of the full projected lifetime. A separate test facility is needed because a high yearly fluence would not be expected from an ETR, which would combine a technology/component testing mission and a long-burn demonstration for the first time.

RESOURCE REQUIREMENTS

A preliminary estimate has been made of the resources required to carry out the full set of research and development activities described in the TPA. The reference scenario was used as the basis for this resource estimate. Although considerable uncertainty exists in the details of the estimates, some general observations can be made.

The overall resource requirement for the period 1987-2005 is approximately $20 billion. Although operating costs are nearly constant at $800 million annually, the overall annual funding increases to about $1.5 billion in the mid-1990s, because of construction costs for facilities crucial to providing the required information for the assessment of fusion's potential. The fraction of the budget devoted to technology issues must increase several fold to achieve the desired results. A coordinated worldwide program to achieve the reference scenario would require a redistribution of the

technical effort. In addition, these estimates do not account for duplication of effort in an international program, which is both unavoidable and, to some degree, desirable.

REFERENCES

1. *Magnetic Fusion Program Plan*, U.S. Dept. of Energy, Office of Energy Research, DOE/ER-0214, Feb. 1985.

2. *Technical Planning Activity Final Report*, Argonne National Laboratory Report ANL/FPP-87-1, Jan. 1987.

☆U.S. GOVERNMENT PRINTING OFFICE: 1987–743-330